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INVESTIGATION OF GROUND AND FOUNDATION CONDITION INFLUENCE ON THE SPASO-PREOBROZHENSKAYA CHURCH CONSTRUCTIONS IN POLOTSK

In the article the problems of the XII century architecture monument preservation – Spaso-Preobrazhenskaya church of Spaso-Efrosinievskiy convent in Polotsk are considered. A brief reference is given on the technical condition and design features of the facility. Various parameters research results allows to estimating bearing constructions technical condition. The issues of bearing structure geodetic, visual, instrumental and electronic remote monitoring complex implementation and organization are considered. The issues of innovative technology introduction for this research area such as ground-based three-dimensional laser scanning are covered. There was made a conclusion church foundation conditions and there are given recommendations as for their strengthening.

***Keywords:** foundation, church, architectural monument, laser scanning, monitoring of building structures.*

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ВИВЧЕННЯ ВПЛИВУ ҐРУНТУ ТА ФУНДАМЕНТУ НА БУДІВЛЮ СПАСО-ПРЕОБРАЖЕНСЬКОЇ ЦЕРКВИ В ПОЛОЦЬКУ

Розглянуто проблеми збереження пам'ятки архітектури XII ст. – Спасо-Преображенської церкви Спасо-Єфросиніївського жіночого православного монастиря в Полоцьку. Наведено коротку довідку про технічний стан і конструктивні особливості об'єкта, результати досліджень різних параметрів, які дозволяють оцінити технічний стан несучих конструкцій будівлі. Розглянуто питання впровадження та організації комплексу геодезичного, візуального, інструментального й електронного дистанційного моніторингу несучих конструкцій. Охоплено питання впрвадження інноваційних технологій у цій сфері досліджень, таких як наземне тривимірне лазерне сканування. Зроблено висновок про стан основ церкви та наведено рекомендації щодо укріплення.

***Ключові слова:** фундамент, церква, пам'ятка архітектури, лазерне сканування, моніторинг будівельних конструкцій.*

Introduction. Since the end of the XX century, recovery and restoration work of buildings and structures having historical and cultural value are held. Ancient buildings and structures church appointments significantly differ from other structures in view of their purpose specific nature, actual operating conditions, long life time, building materials features. Deformations and damage of old buildings and structures is bound with natural processes, changes in soil conditions, water balance of the territory, etc. Therefore, the assessment of buildings technical condition is a complex task and requires specific research methods, in particular, the study of the system «structure – foundation».

The latest sources of research and publications analysis. When carrying out work to survey and study changes in the technical condition of load-bearing structures of architectural monuments, it is necessary to comply with the requirements of the current legislation [13 – 16]. The restoration of religious historic buildings and structures is always difficult due to lack of information. This requires studying the experience of domestic colleagues similar studies in foundations surveys and engineering-geological surveys [8, 9]; carrying out of measurement works of architectural heritage objects [11]; monitoring and development of measures to strengthen foundations [10, 12]. Also very valuable in the study of changes in the technical state of structures is the foreign experience [1 – 7].

Reconstruction of cultural heritage each object is a research work from the beginning to its completion.

Allocation of previously unresolved parts of a common problem. The determination of the building, structures and historical monuments actual technical condition was either not carried out or was not carried out completely. It is due to the fact that innovative technical tools were not available for engineers-restorers. Information on the dates and times of changes in the technical condition caused by changes in soil conditions, water balance of the territory, increased aggressiveness of natural factors and the reorganization of the temple, was not preserved, or was not sought in the course of special works. Reconstruction of full-fledged technical documentation of historical and cultural heritage objects with complex geometric parameters is impossible with the use of simple linear measuring instruments.

Formulation of the problem. The introduction of modern innovative software systems and equipment allows performing research at a high technical level. The development of a set of measures to investigate the stress-strain state of the church structures should be oriented towards comprehensive study of the factors affecting it, as well as preserving the old decorative layers that bear high cultural value. The analysis of the research results carried out on the architectural monument of the 12th century – the building of the Spaso-Preobrazhenskaya church of Spaso-Efrosinievskiy convent in the town Polotsk allows developing complex solutions for reinforcing or restoring existing structures and ensuring an acceptable level of facility safe operation.

Technical condition of the object. The Spaso-Preobrazhenskaya church is the oldest historical and cultural monument on the territory of Belarus that has survived till the present day. The history of the Spaso-Preobrazhenskaya church of the of Spaso-Efrosinievskiy convent in the town of Polotsk begins in the 12th century and is closely connected with the activities of the Reverend Efrosinia Polotskaya.

The temple is a cross-domed six-pillar structure with an adjacent porch and a semi-circular apse in the plan (Figure 1). The church has small dimensions: length – 14.4 m (with an apse – 18.2 m), width – 9.8 m, height to the roof ridge – 14.5 m, to the base of the cross on the drum – 22.7 m. The structural basis of the building is a powerful wall with pylons united in an integral system, columns-pillars and cross vaults. All the supporting structures of the XII century are made in the form of masonry on a lime mortar. On the internal plaster layer of the walls, as well as on the plaster surfaces of pillars and arches, mural painting is applied.

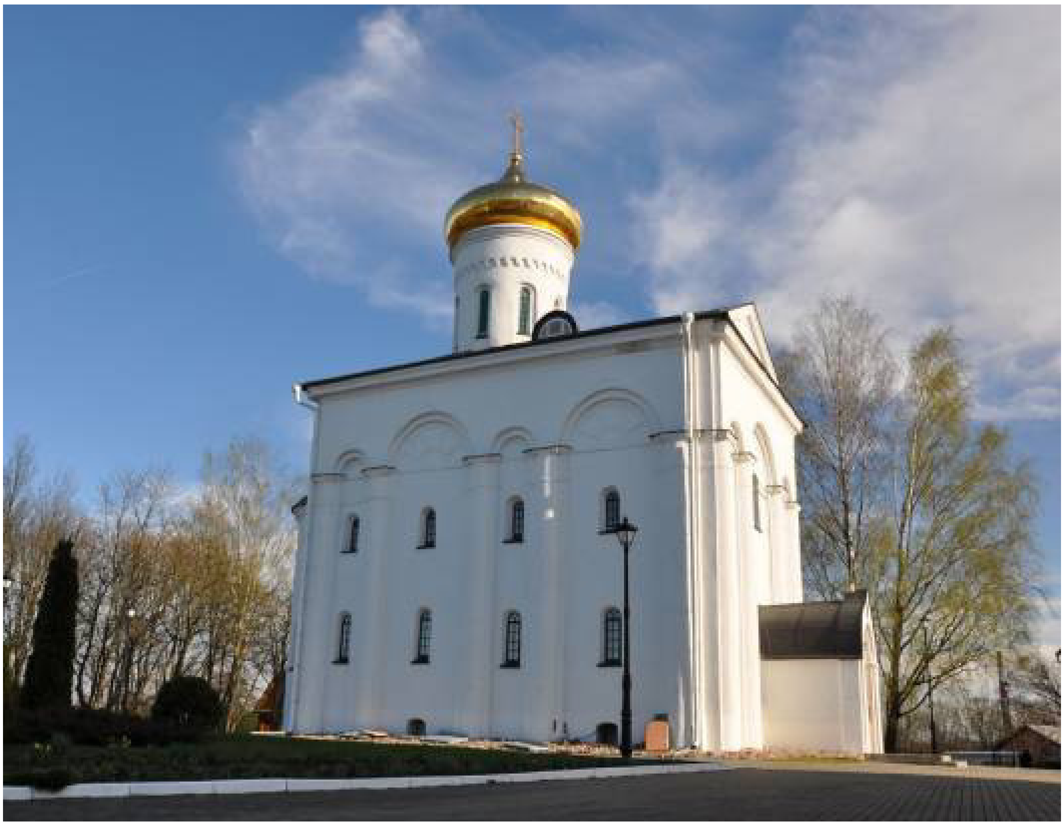

Figure 1 – General view of the Spaso-Preobrazhenskaya church in Polotsk

The appearance of the church has had significant changes in the original form. In the eighteenth century, the first restructuring was carried out by the Jesuits, who from 1580 were its owners. The facades and the roof were changed. The cascade of kokoshniks was hidden by a parapet and pitched roof. For ritual burial grounds, a crypt was built-a basement room with a width of 160 ... 180 cm in the form of a cross covered with brick vaults. At the device of a crypt, probably, foundations have been damaged, since. In the side walls, the openings through which the entrance was made were punched. Also, the level of the floor was raised by approximately 30 ... 40cm, the bottom of the walls of the crypt was arranged approximately at the bottom of the foundations of the main building, and the maximum height of the crypt is 150 ... 170cm. Currently, these three apertures (entrance-laz) are in closed pit covers in the walls of the southern and northern facades.

After the transfer of Polotsk to the Russian Empire, the temple was returned to the Orthodox. Repair work was carried out with a change in the appearance of the temple. The dome over the drum became bulbous. The works on the construction of the bell tower were stopped because of the cracks that appeared in the walls and vaults. The clutch of the bell tower was not dismantled. Work was done to strengthen the walls – the archa-shells were laid, steel straps were installed in the level of the parapet.

The planned restoration of the fresco painting began in the early 90s of the last century and has not been completed yet (Figure 2).

The material for the foundation of the church is rubble stone, laid with incomplete filling of seams. In archaeological excavations there are foundations with the laying of stones «dry» and the presence of residues (decay) of oak stands (Figure 3). The total height of the basement foundation is on the average 90 cm, and the height of the walls masonry is at a certain level below the level of the existing planning mark – about 100 cm. In the masonry wall solution contains a large amount of cement.

Figure 2 – General view of the church structure.
On the walls, arches, pillars, there is a fresco painting of the 12th century

Figure 3 – Results of the structure opening to determine the technical state of foundations under the pillars

Crypta (an underground arched structure for the burial of Catholic priests) was arranged during the period of Jesuits possession by the temple. Partly under the walls, the crypts were made of quarry stone on a limestone mortar with a base height of 300 mm, a width of 320 mm, partly no foundations. The walls of the crypt are made of thick “brick”, the vaults are «half-brick» on the lime mortar.

Within the walls of the church, cracks with different opening widths (from 0.05 to 75 mm) were identified (Figure 4). Cracks have sedimentary character. At the junction of the cell wall with the outer wall there is no bandage between the rows of wall masonry, which allows exchanging between the outer walls and inner pillars. In the pillars longitudinal and transverse cracks are revealed. The pillars have general tendency towards the exterior walls of the building. Longitudinal and inclined cracks are revealed in the laying of the kokoshniks.

According to the totality of moral and physical deterioration signs, the technical condition of the building constructions is generally characterized as unsatisfactory, requiring measures for repair and reinforcement. Physical wear of structures is 40...80%.

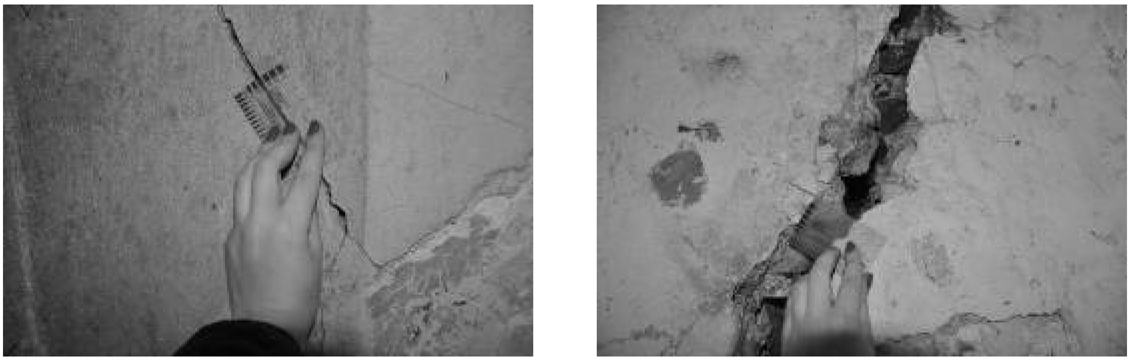

Figure 4 – Measurement of crack opening width in church structures

Monitoring of church buildings bearing structures stress-strain state. The results obtained during the survey showed the need to carry out work to strengthen the church designs and foundations. At the same time, in order to assess the actual stress-strain state of the structures more accurately and to develop measures to strengthen them, additional studies are needed (determining the properties of the foundation soils under the foundations soles, characteristics, considering the nonlinear stage of work and the actual pressures under the soles, clarifying the depth and width soles). In this situation, the most expedient solution was to monitor the stress-strain state of the building and the dynamics of crack opening in the above-ground structures.

Researches were done to monitor the stress-strain state of construction works to carry out joint projects of the research and production unitary enterprise «Stroyrekonstruktsiya» and the «Bridges and Tunnels» Department of the Belarusian National Technical University.

Monitoring provides for continuous monitoring in full-scale conditions for deformations and forces in the supporting building structures of the church and verification of their compliance with design values ensuring accident-free operation of structures, and includes: geodetic; visual; instrumental; electronic remote monitoring and scientific support of monitoring activities [17].

For geodetic monitoring inside and outside the temple geodetic marks were installed, with the help of which observations were made of the draft and deformations of the temple structures. In addition, a laser scan was performed, which will install deflections and rolls of load-bearing structures for a more complete analysis of the processes occurred during the time of existence.

The obtained scan results were subsequently transferred to correct the calculation model, performed in accordance with the previously existing approximate dimensional drawings. It should be noted that the application of the above technology allows making the amount of work that various specialists have tried to do for many decades (Figure 5).

During the visual monitoring, all the defects and damages were photographed, the initial geometric dimensions of the defects were recorded, maps of the cracks and the route were compiled for their control [18]. The deformations and damage to the building were caused by natural processes, modern technologies related to physical and material resources revealed during the control process, significantly accelerating the aging of building materials.

When instrumental monitoring, stationary beacons were installed to control the width of the crack opening by «Concretes and building materials» of the Belarusian National Technical University. The study of all the computational information was incorporated into the design model of the structures. In addition, a qualitative chemical analysis of a brick sample and masonry mortar was performed to determine the presence of soluble salts of carbonates in the masonry of the temple.

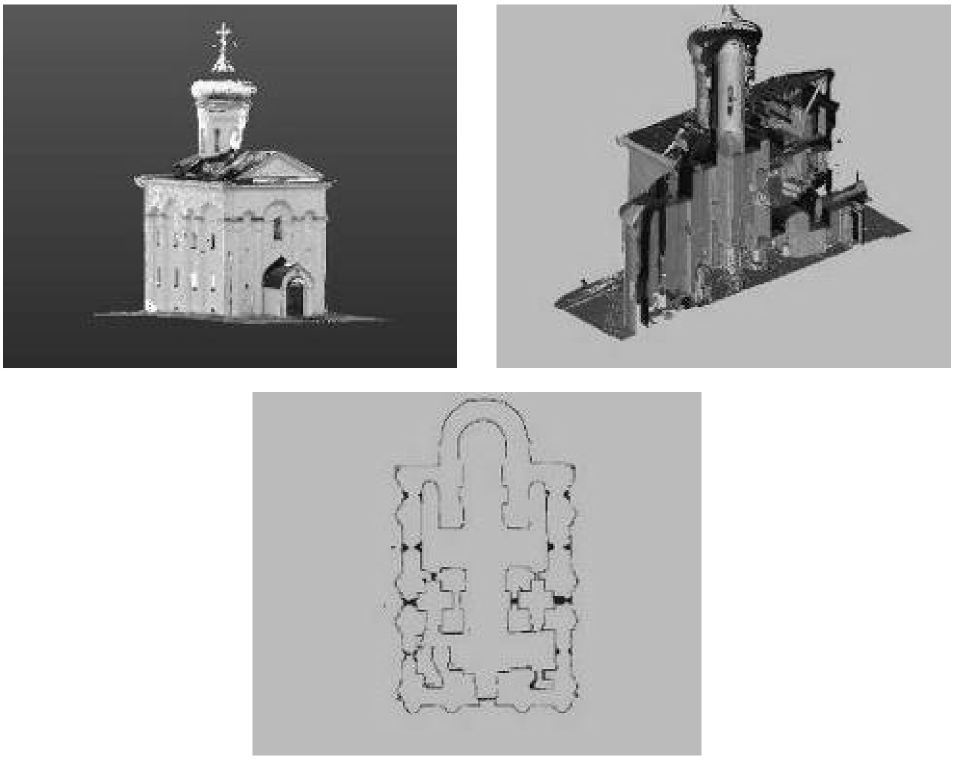

Figure 5 – Some results of a three-dimensional ground-based laser scanning of a church building. General view of the points cloud, a cut, a plan in the level of the choir

In the church it was controlled the temperature-humidity regime [19], in particular, using thermal imaging. As a result of the study, thermal bridges with obvious heat losses were identified; the actual irregularities in the distribution of the field temperature on the wall surface were revealed, indicating a degradation of the thermal protection characteristics of the finishing materials; places with high humidity were identified.

In the course of electronic monitoring, the state of structures was determined, the appearance and rise of groundwater level in the crypt and its fixation in quantitative terms, the angles of of the building parapets walls, the width of crack opening at characteristic points, and the temperature change in the church in height and area. For convenient analysis, the data was provided in the form of graphs (Figure 6).

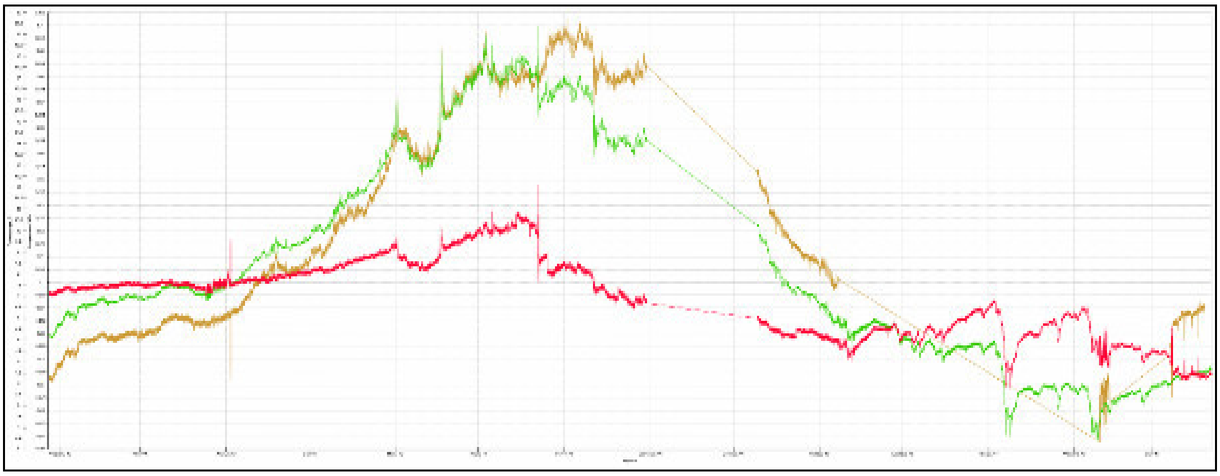

Figure 6 – Graph of changes in temperature and stresses occurring in pillar structures from December 2015 to March 2017

When analyzing the data of load-carrying structures electronic monitoring, it is established that not all structural elements work in the same way with temperature changes and the effect of temporary loads. The work of two pillars and the southern wall does not correspond to elastic work. The change in their stress-strain state cannot be simulated and, in some cases, works separately from the basic structures of the church. This is due to the base sediment and the insufficient bearing capacity of the foundations. The work of the crypts pillars is complicated, toward which the foundations of the pillars are shifted. It is necessary to take urgent measures to strengthen the foundation and foundations under the pillars. The crypt walls do not work in the elastic stage, deforming the stent inside the crypt. There is no unification of the crypt walls with the arch. The ability of walls to perceive Effective loads from ground pressure and loads transmitted from the pillar can be lost if the necessary measures are not fully implemented.

Engineering and geological surveys using static and dynamic sounding. The work was carried out by the employees of Vitgeostroy LLC and OOO Ecotechcontrol LLC. During engineering and geological surveys and at the same time there were carried out archaeological research, the main purpose of which is the most complete study of the cultural layer for the reconstruction of history, the architectural appearance of the temple surrounding their territory, and the collection of documentary data to justify restoration solutions.

When performing the refined, 7 pits were made (Figure 7).

Figure 7 – General view of the pit on the south side of the temple

Geomorphologically, the area belongs to the lake-glacial plain formed during the period of the otzyzer glacier retreat. The relief is in a state of stable equilibrium. Modern active physico-geological processes and phenomena are not observed.

The climate of the region is transitional from marine to continental, characterized by warm, humid winters and a cool rainy summer. According to SNiP 2.01.01-82, the survey area refers to the II «B» climatic zone.

The hydrogeological conditions of the site are characterized by the presence of groundwater. Groundwater is represented by perch, formed on the roof of lake-lacustrine loams in bulk soil.

Ground substrates under the foundations of the church show heterogeneity in their properties. There are 2 types of soil in underground structures: in the southeastern part of the temple, under the foundations are tug-loamy loams and (type I), in the northwestern part - soft-clastic loams (type II)

The values of the strain modulus for Type I soils are 32-35 MPa, for type II soils it ranges from 17 to 24 MPa. The amount of adhesion is 45 – 66 kPa for type I soils and 49 – 58 kPa for type II soils. The value of the angle of internal friction for soils of the type I type varies from 12 ° to 28 °, for soils of the base of type II – 13 – 14 °.

The values of the strength and deformation properties obtained in the framework of the present studies on the basis of the results of static and dynamic sounding for soils lying under the foundations or near the foundations of the temple are generally higher than the values of similar indicators found earlier for soils not compacted under the influence of the structure. This conclusion is supported by static and dynamic sounding data. For loam type II loam, the difference in the modulus of deformation of soils compacted by the building (E = 24 & 25 MPa) from uncompacted (E = 18 MPa) is well traced. For soils of type I loam this difference is much less: under the foundations E = 34 MPa, outside the foundations E = 32 MPa.

Engineering and geological survey results revealed that under the foundations of the Spaso-Preobrazhenskaya church there are no wooden elements to strengthen the soil base. The main influence on the hydrogeological conditions of soils occurrence of the church foundation is closely related to atmospheric precipitation. According to the data of electronic piezometers and stationary observations of the groundwater level, a regularity in the increase of groundwater level in observation wells was revealed, depending on the amount of precipitated precipitation. Underflooding of the temple basement part causes regular humidification of wall structures due to capillary water uplift, deterioration of strength and deformation properties of materials of structural elements, formation of high temperatures on their surface and traces of biopores.

Based on the analysis of the study results, changes in the technical condition of the church supporting structures are recommended to strengthen the existing foundations.

Strengthening of foundations must be performed with the use of restoration materials or materials prepared on the basis of spectral analysis of ancient material selected samples. The aforementioned condition was agreed with the restorers and it is necessary to preserve the authenticity of the object.

In the places of absence or rubble foundations boulders selection, a bookmark of new ones is necessary. Formed cavities between the boulders of foundations should be filled with a lime solution.

It is necessary to conduct all the works to strengthen foundations under the continuous supervision of specialists using the latest equipment to prevent the deterioration of the church structures state or emergency situations.

Conclusions:

1. It is necessary to develop normative documents regulating the conduct of survey works to study the stress-strain state of historical and cultural heritage sites that will ensure the maximum preservation of cultural heritage in terms of objects authenticity.

2. Introduction of innovative technologies in the above-described work allowed with a sufficient degree of quality to determine all the parameters necessary for study were the reasons for the deterioration of the object technical condition have been clarified.

3. It is needed a comprehensive systematic approach to the analysis of archaeological data, technical characteristics of the object and geological studies.

4. The solutions proposed by the authors for strengthening the foundations of the cultural heritage object make it possible to preserve the authenticity of the building.

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